RI 8924

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Bureau of Mines Report of Investigations/1985

Comparative Laboratory Evaluation of Resin-Grouted Roof Bolt Elements

By John R. Bartels and Deno M. Pappas

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

Library of Congress Cataloging in Publication Data:

Bartels, John R

Comparative laboratory evaluation of resin-grouted roof bolt elements.

(Report of investigations ; 8924)

Bibliography: p. 14.

Supt. of Docs. no.: I 28.23:8924.

1. Mine roof bolts, Resin—Testing. I. Pappas, Deno M. II. Title. III. Series: Report of investigations (United States. Bureau of Mines) ; 8924.

TN23.U43 [TN289.3] 622s [622'.28] 84-600267

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	lbf/in	pound (force) per inch
ft·lbf	foot pound (torque)	lbf/in^2	pound (force) per square inch
in	inch	min	minute
lb/ft^3	pound (mass) per cubic foot	pct	percent
lbf	pound (force)	s	second

COMPARATIVE LABORATORY EVALUATION OF RESIN-GROUTED ROOF BOLT ELEMENTS

By John R. Bartels[1] and Deno M. Pappas[1]

ABSTRACT

In laboratory testing, the Bureau of Mines established criteria by which common resin-grouted roof bolting systems can be evaluated and compared. Ultimate strength and stiffness were determined for nontensioned full-column, point-anchor, tensioned full-column, and debondable resin-grouted bolts, and for variations on full-column bolts. Bolt performances were compared using the performance of the 3/4-in full-column resin-grouted bolt as the standard. New and innovative systems can also be qualitatively compared against this standard.

Since the medium into which a resin-grouted bolt is installed is one of the most important parameters affecting bolt performance, various host mediums were used in the testing: sandstone, concrete, simulated coal, simulated shale, and plaster. Bolt performances expected in other mediums can be inferred from the response patterns obtained in these mediums.

Results indicate several functional differences among bolt types. Where resistance to shear is important, point-anchor bolts may outperform nontensioned full-column bolts at a lower cost. In medium- to soft-strength rock, tensioned full-column bolts perform best. Also, varying the resin-steel ratio seems to have little effect on the properties of a full-column bolt, when proper resin mixing is ensured.

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INTRODUCTION

Resin-grouted roof bolts have been the object of numerous investigations since their introduction in the early 1960's. However, the laboratory testing has never covered a comprehensive range of bolt properties as a function of varied rock properties. The objective of the present study was to determine the properties of various bolts installed in a variety of host mediums under laboratory conditions and to produce a table of baseline values that could be used to compare and evaluate resin-grouted mine roof bolting systems.

The bolting parameters chosen for this study were those considered most useful in selecting roof support. The bolt properties considered most useful for comparative evaluation were ultimate strength, as a measure of the maximum load a bolt can carry without appreciable loss of integrity, and stiffness, as a measure of bolt system elasticity and effectiveness in providing stress relief of strata. (The modulus of elasticity cannot be determined for these systems since the effective area cannot be defined.) The properties of the host mediums into which the resin-grouted bolts were installed that were projected to have the greatest influence on bolt properties were shear strength, compressive strength, tensile strength, and hardness.

Tests were performed on four types of resin-grouted bolts, as well as on a number of modifications to the standard full-column resin bolt. Bolting deficiencies resulting from voids in the resin column were also examined. Such deficiencies could typically result from carelessness during bolt installation or separations in the bolted strata. Additionally, tests were made on varying the resin-steel ratios of a full-column bolt installation and using hollow steel cores for full-column resin bolts, to determine whether these systems would provide improved or equal support at lower cost.

Bolt properties were determined for both an axial tension loading and a horizontal shear loading; these reproduce the most common underground bolt loading modes (1-4).[2] All data were tabulated into a matrix of properties (stiffness and ultimate strength).

MATERIALS AND BOLTING SYSTEMS

The host mediums, selected to cover a range of rock properties, were sandstone, concrete, coal, shale, and plaster. All of these sample mediums, with the exception of sandstone, were quality-controlled mixes (table 1). The properties of the simulated coal and shale approximated those of the original materials. Concrete and plaster do not simulate a particular rock type, but their properties do lie in the ranges of such rocks as limestone or mudstone. The laboratory production of sample mediums results in uniform properties, assuring consistent results not possible with field samples, which permit a direct comparison of different bolt types installed in the same medium. The mediums ranged from a very hard competent material to a very soft incompetent material (table 2). Although these mediums were not specifically designed to duplicate a set of underground situations and test results using these mediums cannot be used to predict in-mine values, their diversity provides a means of comparing bolt responses that will permit more rational selection of the best bolt for a particular rock type.

---

[2]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

TABLE 1. - Host medium specifications

Components	Specific gravity	Unit weight, lb/ft^3	Volume ratios, parts	Remarks
Sandstone...........	2.16	135	NAp	Massillon, equivalent to Berea sandstone in quality.
Concrete:				
Sand...............	2.66	166.0	3	Well-graded medium sand.
Cement............	3.16	197.2	2	Portland type II, air entrained.
Water.............	1.00	62.4	.75	
Coal:				
Crushed coal......	1.27	79.2	10	From Bureau's Safety Research Mine.
Fly ash...........	1.86	116.0	8	
Cement............	3.16	197.2	1	Portland type II, air entrained.
Water.............	1.00	62.4	1.5	
Shale:				
Crushed shale.....	2.25	140.4	10	From Bureau's Safety Research Mine
Fly ash...........	1.86	116.0	5	
Cement............	3.16	197.2	1	Portland type II, air entrained.
Water.............	1.00	62.4	1	
Plaster:				
Modeling plaster..	2.57	160.4	1	Type IV (ASTM C-28).
Water.............	1.00	62.4	1	

NAp Not applicable.

TABLE 2. - Host medium properties

	Specific gravity	Strength, lbf/in^2			Shore hardness
		Compressive	Shear	Tensile	
Sandstone.....	2.16	4,929	1,500	350	12
Concrete......	2.11	3,375	853	268	11
Coal..........	1.44	601	176	70	15
Shale.........	1.89	557	167	70	11
Plaster.......	1.76	751	207	75	5

Four bolting systems using resin-grouted bolts were tested: full column, point anchor, tensioned, debondable, and several modifications to the full-column system. Faslok T[3] resin cartridges and grade 40 steel reinforcing bars (rebar) (table 3) were used in all the tests. The following are brief descriptions of each bolting system (fig. 1):

TABLE 3. - Grade 40 rebar properties, pounds (force)

Bolt size, in	Min yield load	Ultimate load
5/8............	12,400	21,700
3/4............	17,600	30,800

[3]Reference to specific products does not imply endorsement by the Bureau of Mines.

1. A standard full-column resin bolt consists of a 2-ft by 3/4-in-diam rebar and enough resin to completely fill a 1-in-diam hole. This is the most commonly used resin-grouted system. Thus, it is used as the basis of comparison for all other resin-grouted systems.

2. Two types of point-anchor resin bolt systems were evaluated. These perform the same function as a mechanically anchored system with a "near perfect anchor." One system consists of a 2-ft by 3/4-in-diam rebar, threaded at one end, which is installed in a 1-in-diam hole with enough polyester resin to grout half (1 ft) of the bolted length. After the resin sets, the bolt is torqued until the Strainsert bolt indicates 6,000 lbf of tension (approximately 150 ft•lbf). The

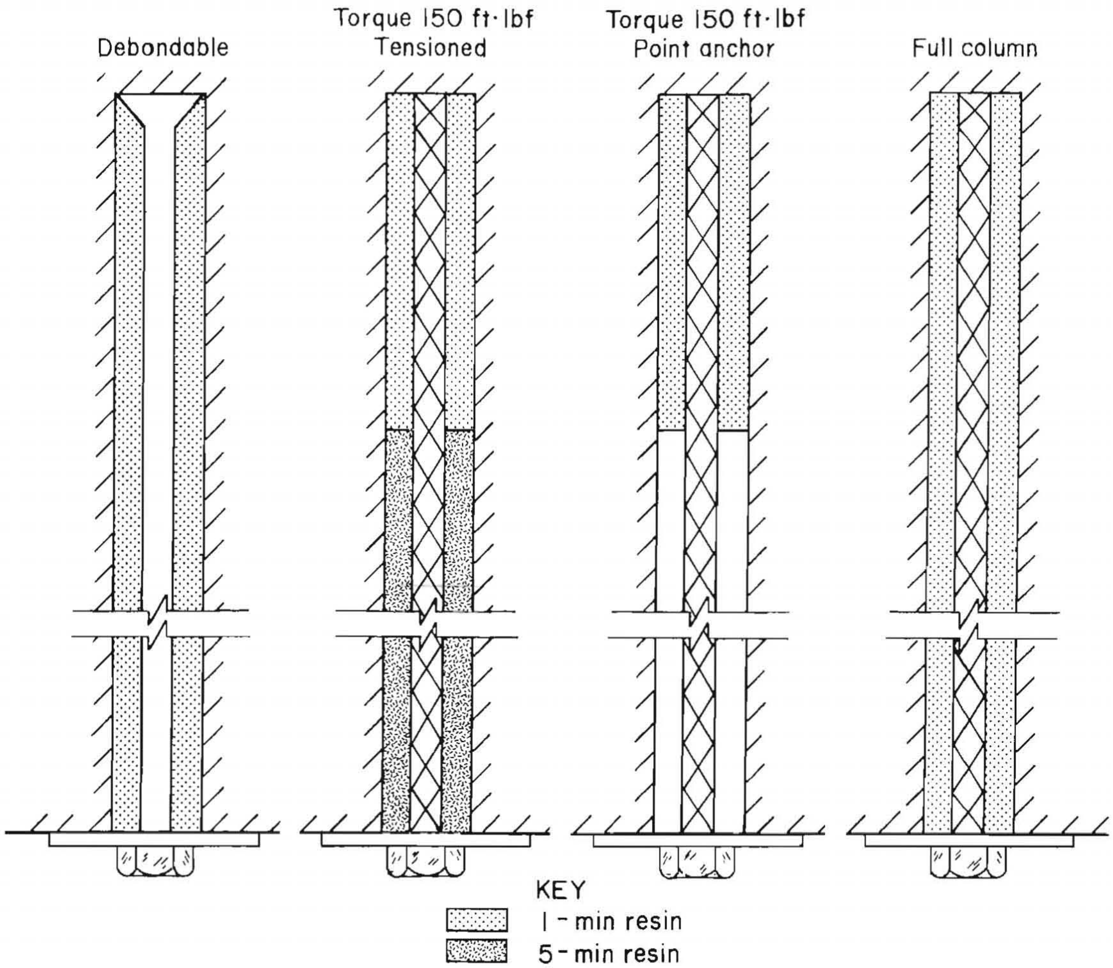

FIGURE 1. - Resin bolting systems.

alternative system consists of a 1-1/4-in-diam rebar anchor that is 1 ft in length and is tapped to accept a threaded 5/8-in-diam high-strength steel rod of the same length. This system is installed in a 1-1/2-in-diam hole with enough polyester resin to completely grout the rebar anchor (1 ft).

3. A tensioned resin bolt consists of a 2-ft by 3/4-in-diam rebar grouted completely with polyester resins of different setting times (1 and 5 min). The fast-setting resin is placed at the far end of the hole and the slow-setting resin at the front. After the 1-min resin has set and before the 5-min resin gains appreciable strength, the bolt is torqued until 6,000 lbf of tension (approximately 150 ft•lbf) is indicated by a Strainsert bolt. Thus, the tensioned bolt combines the mechanisms of both point-anchor and full-column resin bolts.

4. A debondable resin bolt consists of a smooth 2-ft by 3/4-in-diam steel bar with a plug on the end (fig. 1), which is completely grouted with polyester resin. When the bolt is loaded, the steel-resin interface breaks down and the plug at the top of the bolt bears against the entire column of resin (5-6).

5. Modifications to the full-column resin-grouted system included--

a. Varying the resin-steel ratio, which should be of benefit in very soft material where no additional bolt strength is required but failure occurs in the shear mode at the rock-resin interface. Increasing the hole size and thus the shear area of the interface would decrease this problem. Four resin-steel ratios were selected as modifications to the usual ratio (0.777) of a full-column resin bolt:

Bolt, in	Hole, in	Resin-steel ratio
3/4	1-3/8	2.36
3/4	1-1/2	3.00
5/8	1	1.56
5/8	1-3/8	3.84

b. Adding mixing paddles to the test bolts, to prevent the problem of improper mixing of the resin that occurs whenever there is a greater than 3/8-in differential between the hole size and bolt size (6-8). The mixing paddles consisted of spots of weld material located every 3 in along the length of the bolt. These paddles would be necessary on any bolts in actual use and should be considered an integral part of the bolt system.

c. Simulating bolt system deficiencies by adding modeling clay to the resin matrix to produce voids, by reducing the mixing time so that setting of the resin was incomplete, and by hollowing out the bolt's center portion to reduce the cross-sectional area of the bolt.

SAMPLE PREPARATION

Previous tests on resin bolts showed that the significant factor in any bolt installation is the type of material in which the bolt is installed (4, 7, 9). This necessitated testing in a variety of host mediums representing a wide range of roof rock properties, as discussed in the previous section. Since time considerations precluded testing all rock types, representative types were chosen, from which interpolations can be made. Tests were first conducted in concrete; these were used as a basis for comparing properties since concrete offers a consistency of properties among specimen samples that is unobtainable with other mediums. The remaining tests were performed in plaster, shale, coal, and sandstone. The coal and shale host mediums were simulations (mixed according to table 1), since the friable nature of the actual materials made it impossible to obtain samples of sufficient size or quality for the test procedures.

For the axial tension tests, the formulated host medium samples were poured in 24-in lengths of 10-in-ID PVC (polyvinyl chloride) pipe. For shear testing, the samples were poured in two identical sections consisting of 10-in-ID PVC pipe 12 in long. All samples were allowed to cure for 28 days. The various types of bolts were then installed (according to the manufacturer's instructions) into the host mediums. A time period of at least 7 days lapsed before testing began.

The sample size was selected based on previous tests performed on resin bolts (4, 7, 9). In the previous tests it was observed, and measured with strain gauges, that failure zones along the rock-resin interface do not propagate more than 4 in around the circumference of the bolt or more than 8 in along the length of the bolt from the point of load application.

TESTING PROCEDURE

The axial tension test procedure was initiated by placing a hollow 20-ton hydraulic ram and donut-shaped bearing plates around the exposed portion of the installed roof bolt. The roof bolt was attached to a threaded coupler that in turn was attached to a Strainsert bolt to obtain exact tension readings (figs. 2-3).

Tensioned and point-anchor bolts were then torqued until the Strainsert bolt indicated 6,000 lbf of tension.[4] Bolts were loaded with the hydraulic ram and displacement readings taken from two LVDT's (linear voltage displacement transducers) placed on either side of the bolt bearing plate. Readings were taken every 1,000 lbf as indicated by a 20,000-lbf/in^2 pressure gauge, a pressure transducer, and the Strainsert bolt. A data acquisition system printed out all necessary information (fig. 4). All readings were taken until failure. Failure was considered to be either when the bolt broke or when the bolt-resin-rock system could no longer support the applied load without appreciable displacement (at about 0.1 in of deflection for 1,000 lbf of increased load).

The testing procedure for the shear tests consisted of shimming the bolt-host rock system into a loading frame incorporating a 30-ton actuating ram located as close to the interface of the two block halves as possible (figs. 5-6). An LVDT was placed on the side of the top block opposite the ram. Tensioned and point-anchor bolts were torqued to approximately 150 ft•lbf (6,000-lbf tension reading). Displacement and pressure readings were taken for every 1,000 lbf of loading (as indicated by a pressure gauge and pressure transducer) until failure (0.5 in of displacement or when the test sample crushed).

[4]This is the minimum torque required by the Mine Safety and Health Administration (MSHA) and is thus the most common torque.

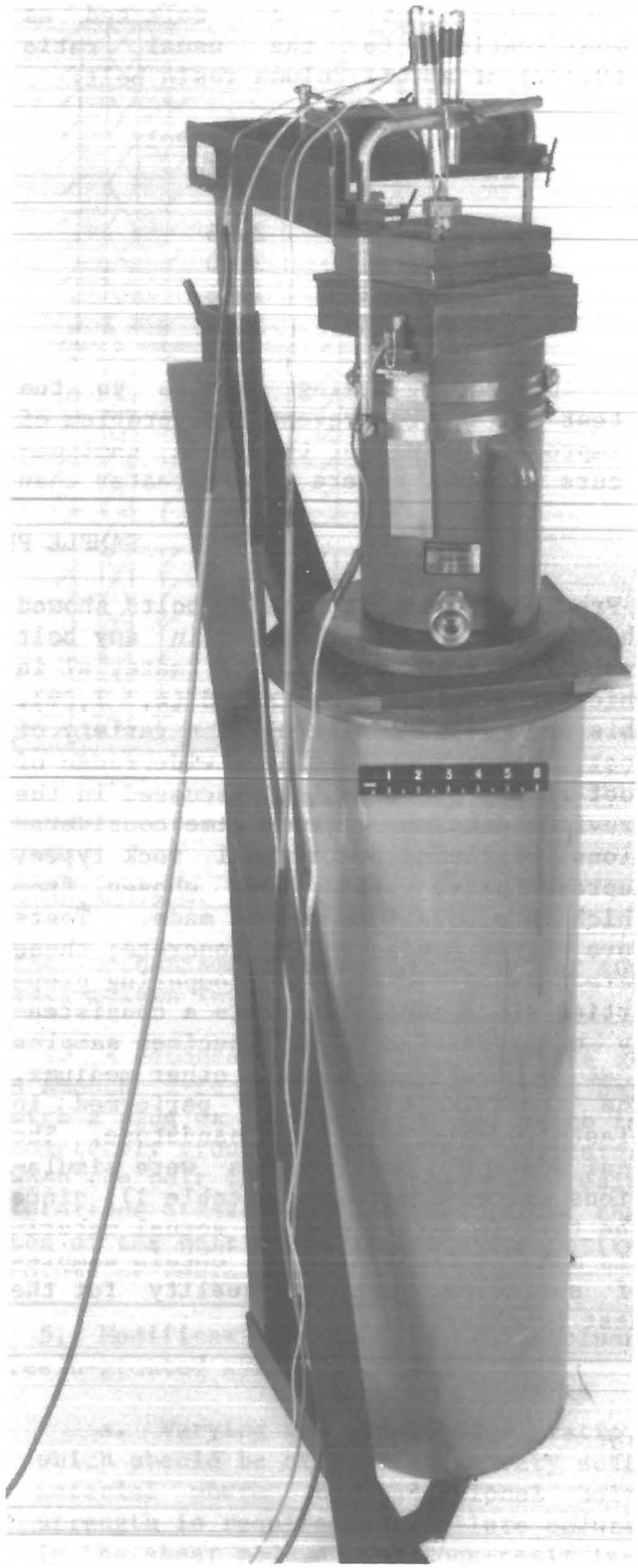

FIGURE 2. - Axial tension test setup.

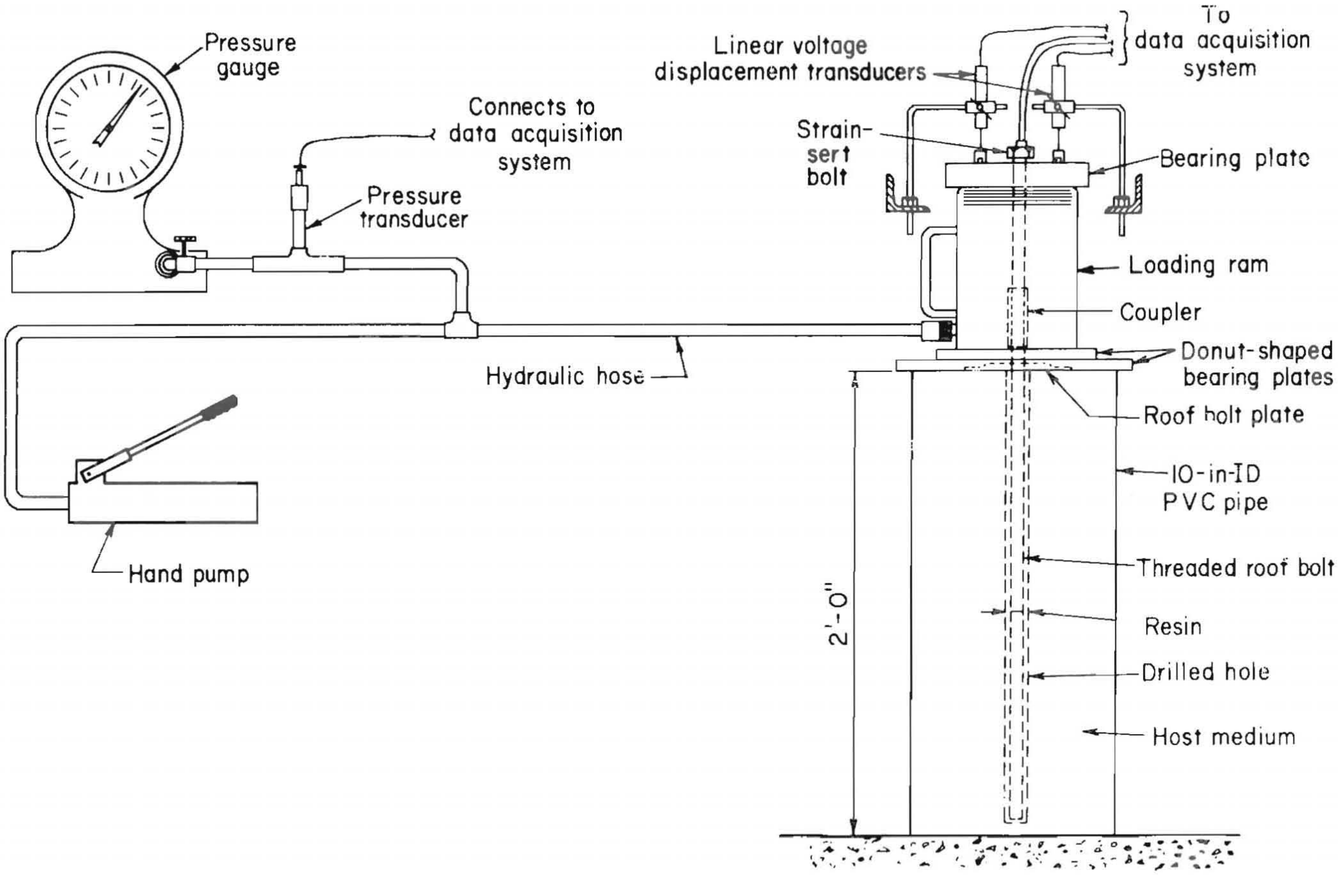

FIGURE 3. - Diagram of axial tension test setup.

TEST RESULTS

All values of ultimate strength and stiffness are averages, usually of five tests. Ultimate strength values correspond to the highest load obtained in 1,000-lbf increments before the bolt could no longer support the load. The stiffness values were determined by calculating the slope of the elastic portion of each load-versus-displacement curve and averaged (fig. 7). The ambiguous portions of the curve were dropped where system slack required 1,000 to 3,000 lbf of load to be taken up and where the systems became totally plastic for the last several 1,000-lbf increments prior to bolt failure. Load-versus-displacement curves were, however, very linear throughout the middle range.

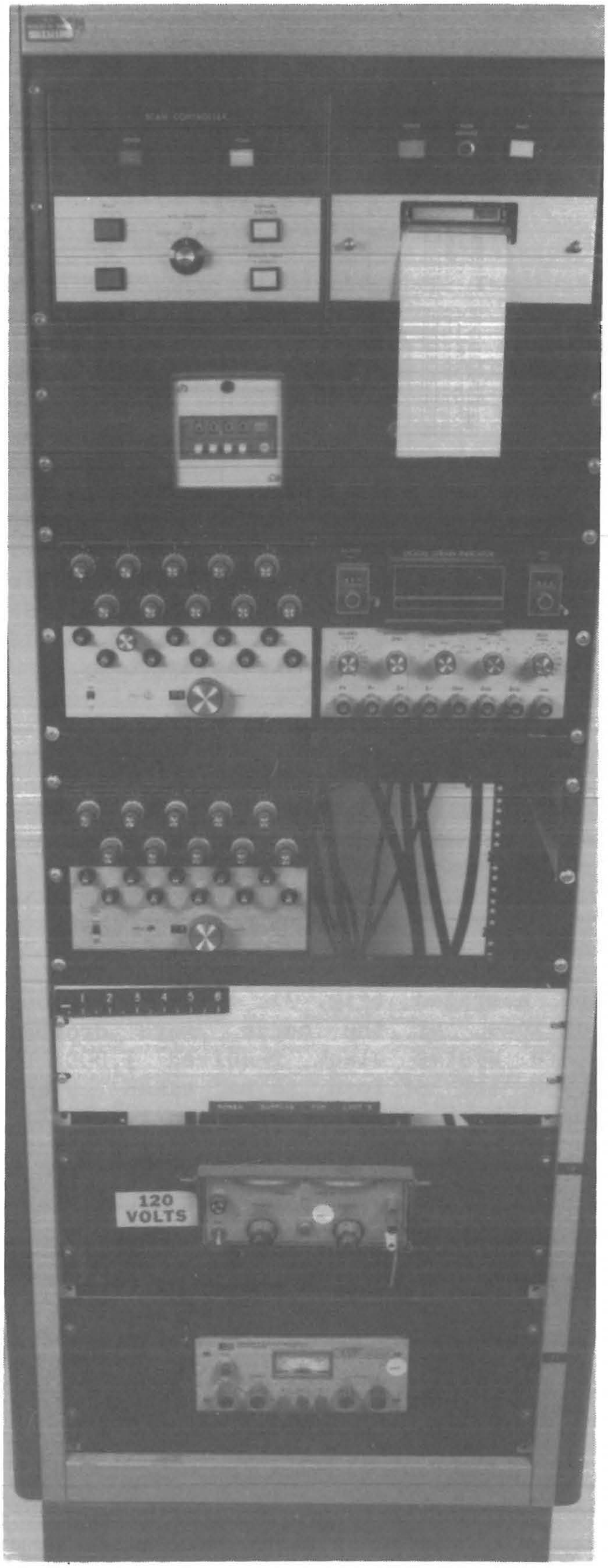

FIGURE 4. - Data acquisition system.

AXIAL TENSION TESTS

The first battery of tests, to determine bolt properties resulting from axial tension loads, was the most extensive series. These tests, particularly the initial concrete tests, were the indicators of the feasibility of continuing further tests. An overview of the test results is given in table 4, and complete results are listed in the appendix.

All of the tests on varying the resin-steel ratio were conducted in a concrete medium to establish the feasibility of increasing the resin content of a full-column resin-grouted bolt installation. Increasing the resin content did not appreciably decrease the ultimate strength of the bolt system and only slightly decreased the stiffness (when comparing equivalent bolt diameters). These results indicate that it would be useful to evaluate the possibility of increasing bolt effectiveness by increasing the area of rock-resin contact in soft rock (Shore hardness less than 10) where failure consistently occurred by shearing along the rock-resin interface.

Tests of full-column resin bolts were conducted in all five host mediums in order to establish baseline properties in each of the host mediums. Since full-column resin-grouted bolts are the most commonly used resin-grouted system underground, they were used as the standard against which all other resin-grouted systems were evaluated. Property values were close to what would be expected based on previous tests (4). Ultimate strength and stiffness values were high for the more competent host mediums and decreased as the competence (compressive strength and hardness) of the medium decreased.

Two types of point-anchor resin bolt systems were tested. The first system used a standard grade 40 3/4-in rebar threaded on the end. These bolts showed the same pattern of decreasing strength and stiffness with decreasing rock competence as did the full-column resin bolts. However, the values of strength and stiffness were much larger than would

TABLE 4. - Overview of axial tension test results

Test	Size, in		Medium	Ultimate load, lbf	Stiffness, lbf/in	Elastic limit, lbf	Failure
	Bolt[1]	Hole					
Resin-steel ratio:[2]							
1.56................	5/8	1	Concrete..	14,300	142,000	9,000	B
0.777...............	3/4	1	...do.....	23,900	275,000	18,000	B
2.36................	3/4	1-3/8	...do.....	22,300	231,000	18,000	B
3.00................	3/4	1-1/2	...do.....	24,900	202,000	11,000	B
3.84................	5/8	1-3/8	...do.....	13,600	125,000	7,000	B-P
Full-column bolts.....	3/4	1	Sandstone.	23,100	298,000	19,000	B
	3/4	1	Concrete..	23,900	275,000	18,000	B
	3/4	1	Coal......	22,300	214,000	19,000	B
	3/4	1	Shale.....	17,300	159,000	12,000	P
	3/4	1	Plaster...	9,400	57,000	9,000	P
Point-anchor bolts:							
1-1/4-in-diam anchor	3/4	1-1/2	Sandstone.	28,900	240,000	27,000	P
	3/4	1-1/2	Concrete..	30,100	186,000	28,000	B-P
	3/4	1-1/2	Coal......	18,200	134,000	17,000	B-P
	3/4	1-1/2	Shale.....	9,500	104,000	8,000	P
	3/4	1-1/2	Plaster...	7,000	45,900	6,000	P
3/4-in-diam anchor..	3/4	1	Sandstone.	19,900	228,000	19,000	B
	3/4	1	Concrete..	21,100	171,000	16,000	B-P
	3/4	1	Coal......	20,700	154,000	19,000	B-P
	3/4	1	Shale.....	12,900	97,100	9,000	P
	3/4	1	Plaster...	6,600	42,700	6,000	P
Tensioned full-column bolts.	3/4	1	Sandstone.	20,300	227,000	19,000	B-P
	3/4	1	Concrete..	19,900	224,000	19,000	B
	3/4	1	Coal......	19,900	147,000	18,000	B
	3/4	1	Shale.....	19,900	187,000	18,000	P
	3/4	1	Plaster...	16,200	117,000	16,000	P
Anomalies:							
Hollow bolt.........	3/4	1	Concrete..	23,700	227,000	20,000	B
Voids...............	3/4	1	...do.....	23,200	242,000	20,000	P
Debondable bolt.....	3/4	1	...do.....	21,900	253,000	20,000	B-P
Reduced mixing time:							
5-s mix...........	3/4	1	...do.....	20,900	265,000	20,000	B
3-s mix...........	3/4	1	...do.....	19,900	239,000	20,000	B
2-s mix...........	3/4	1	...do.....	4,000	0	0	P

B Bolt broke.
P Bolt pulled out.
[1]Bolt diameter at point of failure is actually 1/8 in smaller than stated because of threading the bolt to adapt to the test instrumentation.
[2]Full-column bolt.

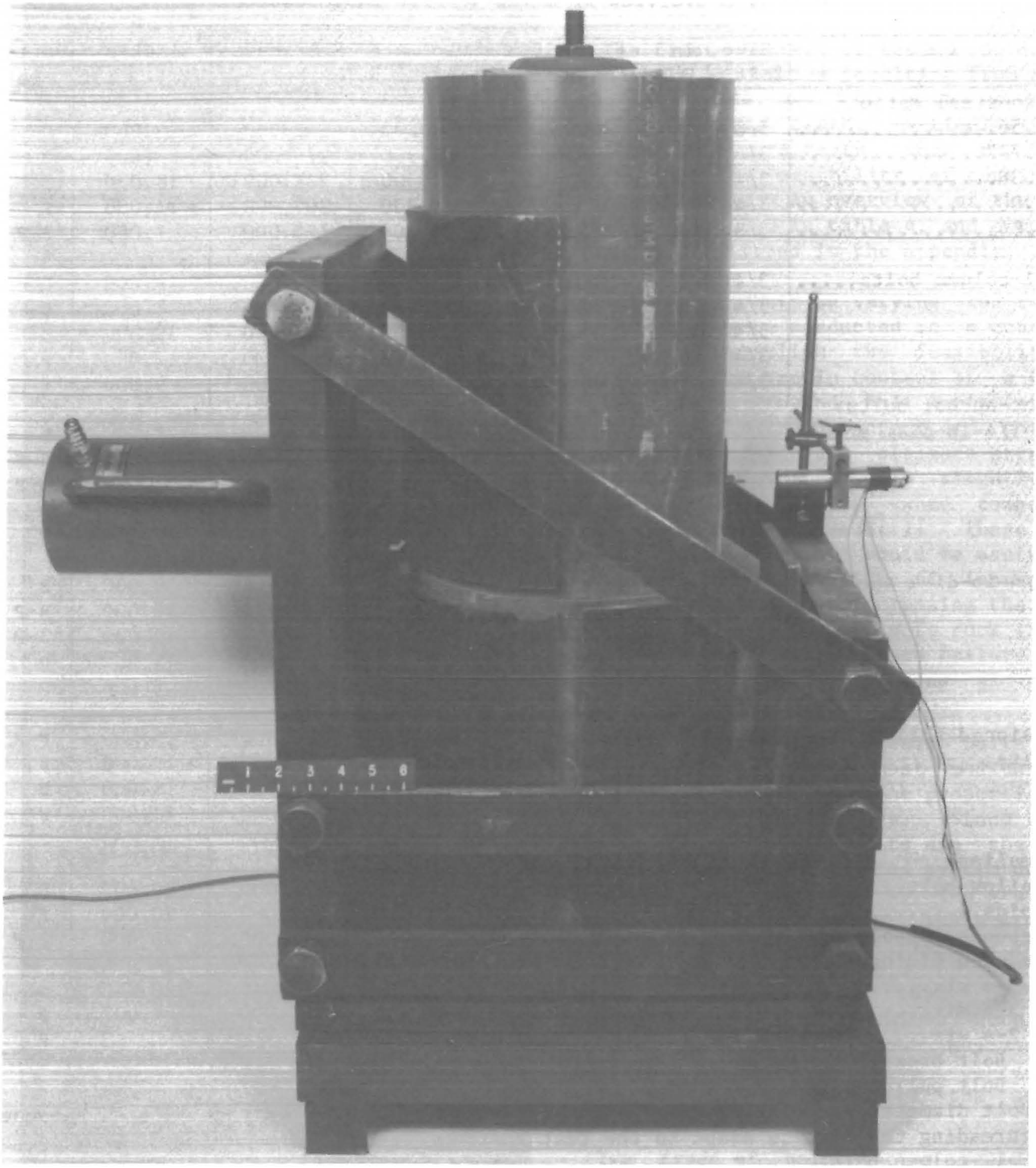

FIGURE 5. - Horizontal shear test setup.

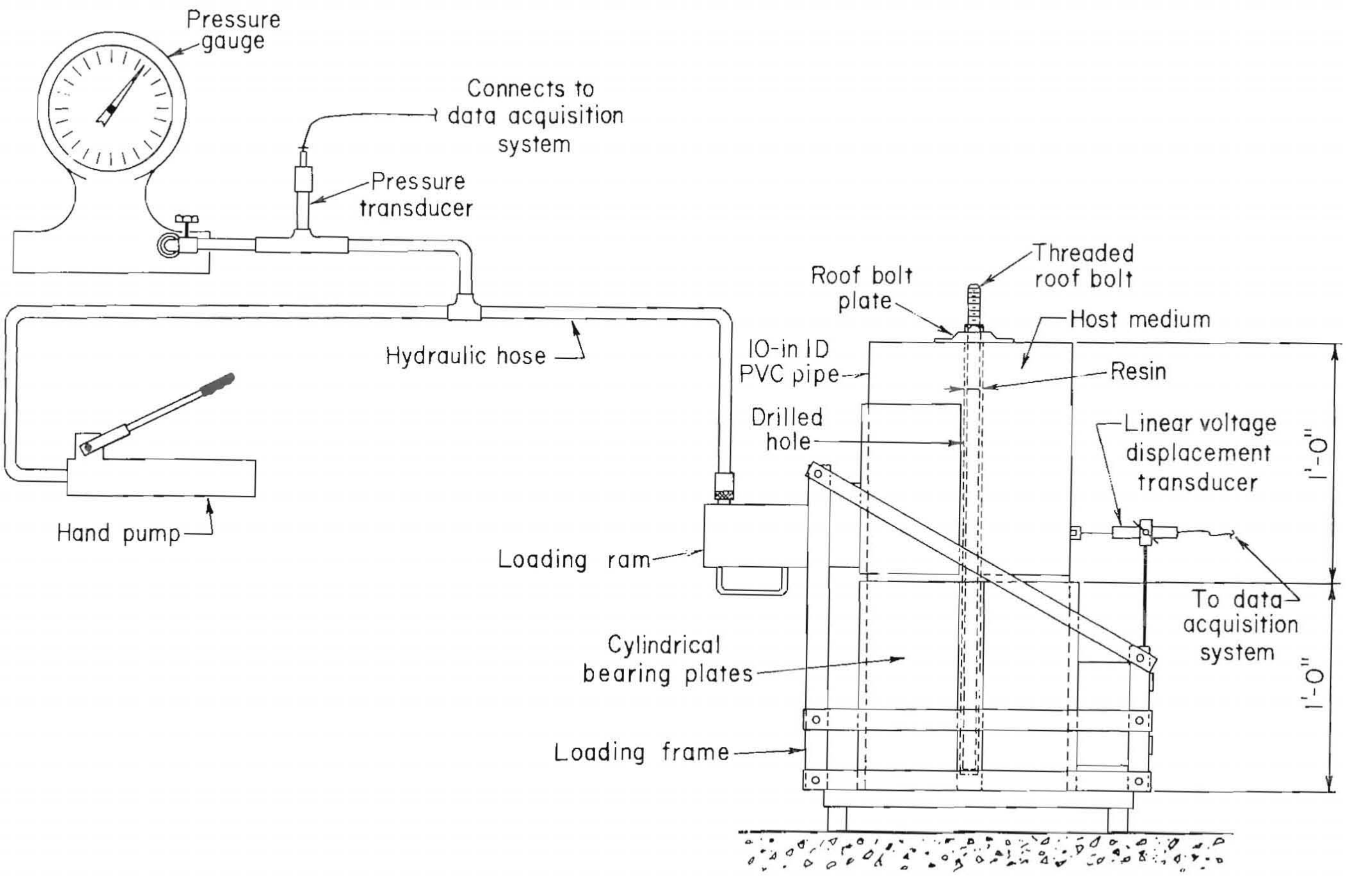

FIGURE 6. - Diagram of horizontal shear test setup.

be expected for a system with half the grouted length of a standard full-column resin bolt. This supports the premise that the length of grout increases bolt anchorage only up to a grouted length of about 2 ft as indicated by previous work (6, 9). This would indicate that, unless the immediate support of the resin column is required at points near the bottom of a bolt installation, point-anchor resin bolts would provide as much tensile support as a full-column bolt at a lower material cost.

The second type of point-anchor resin bolt consisted of a 1-1/4-in rebar anchor with a 5/8-in high-strength steel shank threaded into it. Again, this bolting system lost strength and stiffness in the less competent rock. The strength and stiffness values were not significantly different from those of the 3/4-in point-anchor bolt in the softer mediums. However, they were considerably higher in the high-strength mediums; the steel strength was consistently higher than the strength of the resin-rock interface, resulting in sudden failure along this interface.

Tensioned resin bolts exhibited the most consistent performance of any axial tension loaded bolt. Ultimate strength and stiffness values were uniformly high in all of the mediums, with the exception of plaster, where the values were still higher than those of any other bolt type tested. Apparently, the pretensioning of

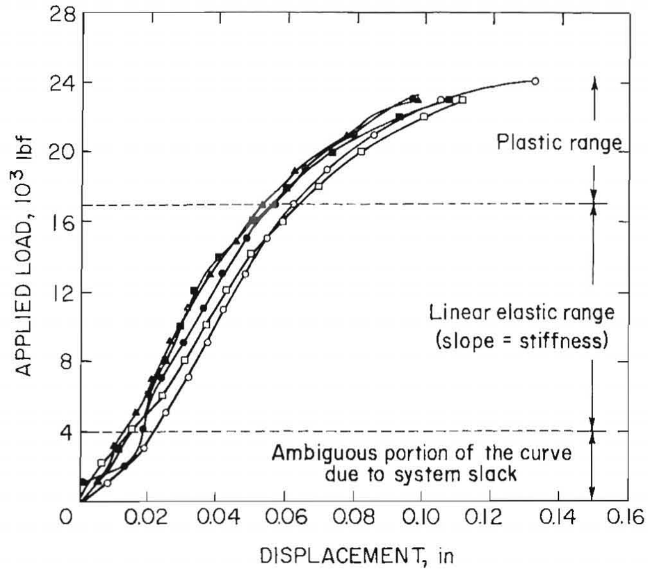

FIGURE 7. - Sample graph of five axial tension tests conducted in sandstone host medium with full-column resin bolt.

the resin column tends to consolidate the rock-resin bond. This system shows the best possibility of stabilizing a wide range of rock types.

Testing of debondable bolts was discontinued after the concrete series. These bolts failed to perform as expected (5), by never debonding along the resin-steel interface. This was indicated by their showing no difference in stiffness or ultimate strength from the standard full-column resin bolt and by subsequent visual inspection.

The tests on bolt system anomalies were a testimonial to the ability of resin to perform under a number of adverse conditions. Hollowing of the bolts (reducing cross-sectional area by 12 pct) had no significant effect on the system strength. Tests on voids created by modeling clay (up to 20 pct of resin volume) indicated that unless the voids are of considerable size or quantity there is no adverse effect on the overall system strength. Finally, resin mixing is incomplete only when virtually no mixing at all occurs, at less than 2 s of spinning time under laboratory conditions (this may vary under actual field conditions).

HORIZONTAL SHEAR TESTS

Because resistance to shear displacement of bedded rock masses is one of the primary advantages of a resin-grouted roof bolt over a conventionally anchored bolt, tests were conducted to determine the shear resistance of the various resin-grouted systems. Failure was arbitrarily set at 0.5 in of horizontal displacement. The test medium usually failed before reaching this displacement. All failures for horizontal shear loading were host medium failures rather than bolt failures, because of the point load exerted on the medium by the resin-grouted bolt's resistance to movement. An overview of the test results is given in table 5, and complete results are listed in the appendix.

Again, all tests on varying the resin-steel ratio were conducted in a concrete medium to establish the feasibility of increasing the resin content in a full-column resin bolt installation. As the resin content was increased, there was a decrease in the ultimate strength and stiffness of the system. This decrease, however, was not significant enough to render the system unfeasible. The overall utility of bolt installations with increased resin contents in soft, friable mine roofs will need further testing.

Ultimate strength and stiffness values for full-column resin bolts in all five host mediums established the baseline values for shear-loaded bolts as they did for axial tension loads. Test results were as expected, with high strength and stiffness values for the more competent mediums and lower values for the less competent mediums. The only exception was the low ultimate strength value obtained for sandstone. This low strength value is due to the fact that sandstone is more brittle than concrete and thus would develop cracks at lower loads than the more elastic concrete.

The only point-anchor bolts tested in a horizontal shear mode were 3/4-in rebar bolts. Increasing the shear

TABLE 5. - Overview of horizontal shear test results

Test	Size, in		Medium	Ultimate load, lbf	Stiffness, lbf/in	Elastic limit, lbf
	Bolt	Hole				
Resin-steel ratio:[1]						
1.56...............	5/8	1	Concrete.....	8,900	30,200	6,000
0.777..............	3/4	1	...do........	15,100	131,000	12,000
2.36...............	3/4	1-3/8	...do........	15,200	116,000	12,000
3.00...............	3/4	1-1/2	...do........	13,300	80,400	9,000
3.84...............	5/8	1-3/8	...do........	9,600	12,300	8,000
Full-column bolts....	3/4	1	Sandstone....	13,100	146,000	10,000
	3/4	1	Concrete.....	15,100	131,000	12,000
	3/4	1	Coal.........	10,100	50,900	8,000
	3/4	1	Shale........	8,200	39,900	7,000
	3/4	1	Plaster......	5,800	15,500	5,000
Point-anchor bolts, 3/4-in-diam anchor.	3/4	1	Sandstone....	15,500	179,000	10,000
	3/4	1	Concrete.....	15,900	120,000	14,000
	3/4	1	Coal.........	11,500	60,000	10,000
	3/4	1	Shale........	10,100	55,500	8,000
	3/4	1	Plaster......	7,000	42,900	5,000
Tensioned full-column bolts.	3/4	1	Sandstone....	14,700	137,000	13,000
	3/4	1	Concrete.....	17,900	94,400	15,000
	3/4	1	Coal.........	9,700	41,600	9,000
	3/4	1	Shale........	8,700	27,300	8,000
	3/4	1	Plaster......	5,400	22,800	4,000

[1]Full-column bolt.

interface frictional force by tension in the bolt moderately increased the ultimate strength of this system over the strength of full-column bolts throughout the range of host mediums.

Tensioned resin-grouted bolts only slightly outperformed full-column bolts in a horizontal shear mode. There were larger ultimate strength values for more competent mediums (sandstone and concrete). However, the ultimate strength values in the remaining mediums were essentially the same. These results may be due to the intermixing of the fast-setting resin and the slow-setting resin around their area of contact. This would make it difficult to assure that the shear interface used in these tests was within the bolt's tensioned zone.

SUMMARY AND CONCLUSIONS

It is hoped that the results presented in this report will assist mine operators in rationally selecting roof support systems. The tables provide a convenient means of comparing the various resin-grouted roof bolt options as a function of roof geology and competence. Selecting bolts better suited to the prevailing conditions should reduce the necessity for remedial support later. These tables should also aid in the analysis of possible solutions to problems in remedial support and isolated roof problems. Although they do not cover the entire spectrum of possible roof lithology, it should be possible to interpolate reasonable estimates under most conditions. These tables should also assist in providing baseline data for future theoretical work on resin-grouted bolting systems and should provide a basis against which new bolting concepts can be compared and evaluated.

These tests document that varying the ratio of steel to resin has little effect on the properties of bolts, when provisions are made to ensure proper resin mixing. The only difference is a slight decrease in stiffness when higher percentages of resin are used, compared with the standard installation, which would be expected since the resin portion of the system has a lower stiffness value than the steel.

Further laboratory and field tests are necessary to document the feasibility of increasing the hole size and thus the shear area around the failure interface, which could provide superior support in soft, loose material where an increased resin contact area should reduce bolt failure. The strength loss, when the hole size was increased, was small for an installation in a competent medium, but the proposed strength increase in soft mediums requires more testing to be adequately confirmed.

These tests indicate possible in-mine uses for the various resin-grouted bolt types. Point-anchor bolts would provide as much support as standard full-column bolts in most strata at a lower material cost and should outperform full-column bolts in instances of a laminated roof where increased resistance to horizontal shear is desired. Tensioned full-column bolts would be the best selection for soft, highly fractured strata where a variety of loading conditions exist.

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APPENDIX.--RESIN BOLT TEST RESULTS

TABLE A-1. -- Axial tension test results: resin-steel ratio and resin bolting systems

Size, in: Bolt	Size, in: Hole	Medium	Ultimate load, lbf	Failure	Strength-related properties: Ultimate load, lbf: Average	Ultimate load, lbf: Standard deviation	Stiffness, lbf/in: Average	Stiffness, lbf/in: Standard deviation	Elastic limit,[1] lbf
				RESIN-STEEL RATIO					
5/8	1	Concrete.	15,000	B					
5/8	1	...do....	15,000	B	14,300	1,161	142,247	3,847	9,000
5/8	1	...do....	13,000	B					
3/4	1	...do....	23,885	B					
3/4	1	...do....	24,895	B					
3/4	1	...do....	23,885	B	23,887	711	274,732	8,815	18,000
3/4	1	...do....	23,885	B					
3/4	1	...do....	22,880	B					
3/4	1-3/8	...do....	22,000	B					
3/4	1-3/8	...do....	22,000	B	22,333	596	231,239	1,426	18,000
3/4	1-3/8	...do....	23,000	B					
3/4	1-1/2	...do....	24,000	B					
3/4	1-1/2	...do....	25,905	B	24,933	953	202,079	8,041	11,000
3/4	1-1/2	...do....	24,895	B					
5/8	1-3/8	...do....	11,000	B					
5/8	1-3/8	...do....	15,000	P	13,646	2,291	125,316	2,974	7,000
5/8	1-3/8	...do....	14,937	P					
				FULL-COLUMN BOLTS					
3/4	1	Sandstone	23,885	B					
3/4	1	...do....	22,875	B					
3/4	1	...do....	22,875	B	23,077	452	297,629	6,331	19,000
3/4	1	...do....	22,875	B					
3/4	1	...do....	22,875	B					
3/4	1	Concrete.	23,885	B					
3/4	1	...do....	24,895	B					
3/4	1	...do....	23,885	B	23,887	711	274,732	8,815	18,000
3/4	1	...do....	23,885	B					
3/4	1	...do....	22,880	B					
3/4	1	Coal.....	21,937	B					
3/4	1	...do....	21,937	B					
3/4	1	...do....	22,875	B	22,312	514	214,307	12,327	19,000
3/4	1	...do....	21,937	B					
3/4	1	...do....	22,875	B					
3/4	1	Shale....	19,917	P					
3/4	1	...do....	14,937	P					
3/4	1	...do....	18,906	P	17,319	2,290	159,285	10,554	12,000
3/4	1	...do....	14,937	P					
3/4	1	...do....	17,896	P					

See explanatory notes at end of table.

TABLE A-1. - Axial tension test results: resin-steel ratio and resin bolting systems--Continued

Size, in		Medium	Ultimate load, lbf	Failure	Strength-related properties				Elastic limit,[1] lbf
					Ultimate load, lbf		Stiffness, lbf/in		
Bolt	Hole				Average	Standard deviation	Average	Standard deviation	
FULL-COLUMN BOLTS--Continued									
3/4	1	Plaster..	9,958	P					
3/4	1	...do....	7,000	P					
3/4	1	...do....	10,968	P	9,366	1,503	56,982	4,996	9,000
3/4	1	...do....	8,948	P					
3/4	1	...do....	9,958	P					
POINT-ANCHOR BOLTS, 1-1/4-IN-DIAM ANCHOR									
3/4	1-1/2	Sandstone	28,864	P					
3/4	1-1/2	...do....	28,864	P					
3/4	1-1/2	...do....	28,864	P	28,864	0	239,602	20,223	27,000
3/4	1-1/2	...do....	28,864	P					
3/4	1-1/2	...do....	28,864	P					
3/4	1-1/2	Concrete.	31,895	P					
3/4	1-1/2	...do....	31,895	B					
3/4	1-1/2	...do....	28,864	P	30,076	1,660	185,553	24,208	28,000
3/4	1-1/2	...do....	28,864	P					
3/4	1-1/2	...do....	28,864	P					
3/4	1-1/2	Coal.....	19,916	P					
3/4	1-1/2	...do....	17,896	P					
3/4	1-1/2	...do....	15,947	B	18,166	1,694	134,456	9,529	17,000
3/4	1-1/2	...do....	18,906	P					
3/4	1-1/2	...do....	Void	NAp					
3/4	1-1/2	Shale....	11,978	P					
3/4	1-1/2	...do....	9,958	P					
3/4	1-1/2	...do....	Void	NAp	9,471	2,074	104,429	16,688	8,000
3/4	1-1/2	...do....	7,000	P					
3/4	1-1/2	...do....	8,948	P					
3/4	1-1/2	Plaster..	5,989	P					
3/4	1-1/2	...do....	8,948	P					
3/4	1-1/2	...do....	6,979	P	7,000	1,211	45,906	12,205	6,000
3/4	1-1/2	...do....	5,989	P					
3/4	1-1/2	...do....	7,095	P					
POINT-ANCHOR BOLTS, 3/4-IN-DIAM ANCHOR									
3/4	1	Sandstone	19,917	B					
3/4	1	...do....	19,917	B					
3/4	1	...do....	19,917	B	19,917	0	227,666	5,484	19,000
3/4	1	...do....	19,917	B					
3/4	1	...do....	19,917	B					
3/4	1	Concrete.	20,926	B					
3/4	1	...do....	22,875	B					
3/4	1	...do....	22,875	B	21,100	3,001	171,000	2,871	16,000
3/4	1	...do....	22,875	B					
3/4	1	...do....	15,947	P					

See explanatory notes at end of table.

TABLE A-1. - Axial tension test results: resin-steel ratio and resin bolting systems--Continued

Size, in: Bolt	Size, in: Hole	Medium	Ultimate load, lbf	Failure	Strength-related properties: Ultimate load, lbf: Average	Ultimate load, lbf: Standard deviation	Stiffness, lbf/in: Average	Stiffness, lbf/in: Standard deviation	Elastic limit,[1] lbf
POINT-ANCHOR BOLTS, 3/4-IN-DIAM ANCHOR--Continued									
3/4	1	Coal.....	19,917	P	20,725	1,106	154,216	3,857	19,000
3/4	1	...do....	21,937	P					
3/4	1	...do....	19,917	B					
3/4	1	...do....	21,937	B					
3/4	1	...do....	19,917	B					
3/4	1	Shale....	7,938	P	12,948	4,462	97,116	15,214	9,000
3/4	1	...do....	13,927	P					
3/4	1	...do....	11,979	P					
3/4	1	...do....	19,927	P					
3/4	1	...do....	10,968	P					
3/4	1	Plaster..	7,000	P	6,581	876	42,692	3,296	6,000
3/4	1	...do....	5,989	P					
3/4	1	...do....	7,938	P					
3/4	1	...do....	5,989	P					
3/4	1	...do....	5,989	P					
TENSIONED FULL-COLUMN BOLTS									
3/4	1	Sandstone	20,926	B	20,321	553	226,863	20,470	19,000
3/4	1	...do....	20,926	P					
3/4	1	...do....	19,917	P					
3/4	1	...do....	19,917	B					
3/4	1	...do....	19,917	B					
3/4	1	Concrete.	19,917	B	19,917	0	223,562	11,999	19,000
3/4	1	...do....	19,917	B					
3/4	1	...do....	19,917	B					
3/4	1	...do....	19,917	B					
3/4	1	...do....	19,917	B					
3/4	1	Coal.....	19,917	B	19,917	0	147,302	15,335	18,000
3/4	1	...do....	19,917	B					
3/4	1	...do....	19,917	B					
3/4	1	...do....	19,917	B					
3/4	1	...do....	19,917	B					
3/4	1	Shale....	19,917	P	19,917	0	187,267	18,939	18,000
3/4	1	...do....	19,917	P					
3/4	1	...do....	19,917	P					
3/4	1	...do....	19,917	P					
3/4	1	...do....	19,917	P					
3/4	1	Plaster..	16,958	P	16,150	1,317	116,849	3,850	16,000
3/4	1	...do....	16,958	P					
3/4	1	...do....	15,947	P					
3/4	1	...do....	13,927	P					
3/4	1	...do....	16,958	P					

B Broke. NAp Not applicable. P Pulled out.
[1]Average elastic limit for the entire system.

TABLE A-2. - Axial tension test results: anomalies

(Concrete host medium)

Anomalies	Size, in: Bolt	Size, in: Hole	Ultimate load, lbf	Failure	Strength-related properties: Ultimate load, lbf: Average	Strength-related properties: Ultimate load, lbf: Standard deviation	Strength-related properties: Stiffness, lbf/in: Average	Strength-related properties: Stiffness, lbf/in: Standard deviation	Elastic limit,[1] lbf
Hollow bolt.	3/4	1	23,885	B	23,683	1,321	227,000	1,597	20,000
	3/4	1	22,875	B					
	3/4	1	22,875	B					
	3/4	1	25,905	B					
	3/4	1	22,875	B					
Voids:									
Clay......	3/4	1	19,917	P	23,236	2,878	242,008	98,932	20,000
Caulk.....	3/4	1	24,895	P					
Tape......	3/4	1	24,895	P					
Debondable bolt.......	3/4	1	20,926	P	21,919	805	252,613	43,511	20,000
	3/4	1	22,875	B					
	3/4	1	21,937	B					
	3/4	1	21,937	B					
Reduced mixing time:									
5-s mix...	3/4	1	20,926	B	20,926	NAp	265,295	NAp	20,000
3-s mix...	3/4	1	19,917	B	19,917	NAp	238,805	NAp	20,000
2-s mix...	3/4	1	3,969	P	3,969	NAp	([2])	NAp	([2])

B Broke. NAp Not applicable. P Pulled out.

[1]Average elastic limit for the entire system.

[2]No strength-related properties owing to poor test results.

TABLE A-3. - Horizontal shear test results

Size, in: Bolt	Size, in: Hole	Medium	Ultimate load, lbf	Strength-related properties: Ultimate load, lbf: Average	Ultimate load, lbf: Standard deviation	Stiffness, lbf/in: Average	Stiffness, lbf/in: Standard deviation	Elastic limit,[1] lbf
RESIN-STEEL RATIO								
5/8	1	Concrete................	6,958					
5/8	1	...do..................	12,922	8,946	3,443	30,224	5,516	6,000
5/8	1	...do..................	6,958					
3/4	1	...do..................	16,898					
3/4	1	...do..................	14,910					
3/4	1	...do..................	14,910	15,109	1,089	131,287	3,689	12,000
3/4	1	...do..................	13,916					
3/4	1	...do..................	14,910					
3/4	1-3/8	...do..................	14,910					
3/4	1-3/8	...do..................	14,910	15,141	574	115,901	4,328	12,000
3/4	1-3/8	...do..................	15,904					
3/4	1-1/2	...do..................	13,916					
3/4	1-1/2	...do..................	13,916	13,253	1,148	80,438	13,247	9,000
3/4	1-1/2	...do..................	11,928					
5/8	1-3/8	...do..................	10,934					
5/8	1-3/8	...do..................	7,952	9,609	1,518	12,328	6,587	8,000
5/8	1-3/8	...do..................	9,950					
FULL-COLUMN BOLTS								
3/4	1	Sandstone..............	12,922					
3/4	1	...do..................	11,928					
3/4	1	...do..................	12,922	13,121	1,089	146,261	10,814	10,000
3/4	1	...do..................	12,922					
3/4	1	...do..................	14,910					
3/4	1	Concrete................	16,898					
3/4	1	...do..................	14,910					
3/4	1	...do..................	14,910	15,109	1,089	131,287	3,689	12,000
3/4	1	...do..................	13,916					
3/4	1	...do..................	14,910					
3/4	1	Coal....................	9,940					
3/4	1	...do..................	10,934					
3/4	1	...do..................	10,934	10,139	832	50,931	8,898	8,000
3/4	1	...do..................	8,946					
3/4	1	...do..................	9,940					
3/4	1	Shale...................	8,946					
3/4	1	...do..................	6,958					
3/4	1	...do..................	7,952	8,151	832	39,914	5,238	7,000
3/4	1	...do..................	8,946					
3/4	1	...do..................	7,952					
3/4	1	Plaster.................	4,970					
3/4	1	...do..................	5,964					
3/4	1	...do..................	5,964	5,765	445	15,538	3,233	5,000
3/4	1	...do..................	5,964					
3/4	1	...do..................	5,964					
POINT-ANCHOR BOLTS, 3/4-IN-DIAM ANCHOR								
3/4	1	Sandstone..............	15,904					
3/4	1	...do..................	15,904					
3/4	1	...do..................	12,922	15,506	1,507	178,732	16,785	10,000
3/4	1	...do..................	16,898					
3/4	1	...do..................	15,904					

[1] Average elastic limit for the entire system.

TABLE A-3. - Horizontal shear test results--Continued

Size, in		Medium	Ultimate load, lbf	Strength-related properties				Elastic limit,[1] lbf
				Ultimate load, lbf		Stiffness, lbf/in		
Bolt	Hole			Average	Standard deviation	Average	Standard deviation	
POINT-ANCHOR BOLTS, 3/4-IN-DIAM ANCHOR--Continued								
3/4	1	Concrete	14,910	15,904	1,217	120,000	18,442	14,000
3/4	1	...do	14,910					
3/4	1	...do	17,892					
3/4	1	...do	15,904					
3/4	1	...do	15,904					
3/4	1	Coal	10,934	11,530	1,334	59,960	6,309	10,000
3/4	1	...do	10,934					
3/4	1	...do	9,940					
3/4	1	...do	12,922					
3/4	1	...do	12,922					
3/4	1	Shale	8,946	10,139	1,089	55,503	8,151	8,000
3/4	1	...do	9,940					
3/4	1	...do	9,940					
3/4	1	...do	9,940					
3/4	1	...do	11,928					
3/4	1	Plaster	6,958	6,958	1,217	42,937	4,529	5,000
3/4	1	...do	5,964					
3/4	1	...do	5,964					
3/4	1	...do	6,958					
3/4	1	...do	8,946					
TENSIONED FULL-COLUMN BOLTS								
3/4	1	Sandstone	12,922	14,711	1,474	136,533	16,693	13,000
3/4	1	...do	16,898					
3/4	1	...do	14,910					
3/4	1	...do	14,910					
3/4	1	...do	13,916					
3/4	1	Concrete	20,875	17,892	2,535	94,383	14,951	15,000
3/4	1	...do	17,892					
3/4	1	...do	19,881					
3/4	1	...do	14,910					
3/4	1	...do	15,904					
3/4	1	Coal	8,946	9,741	1,296	41,648	6,255	9,000
3/4	1	...do	8,946					
3/4	1	...do	11,928					
3/4	1	...do	9,940					
3/4	1	...do	8,946					
3/4	1	Shale	7,952	8,747	445	27,296	3,825	8,000
3/4	1	...do	8,946					
3/4	1	...do	8,946					
3/4	1	...do	8,946					
3/4	1	...do	8,946					
3/4	1	Plaster	3,976	5,368	1,133	22,778	7,464	4,000
3/4	1	...do	5,964					
3/4	1	...do	6,958					
3/4	1	...do	4,970					
3/4	1	...do	4,970					

[1]Average elastic limit for the entire system.